Journal of Atmospheric and Solar-Terrestrial Physics 109 (2014) 22–28

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Distinctive features of radiation pulses in the very first moment of lightning events

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ARTICLE INFO

Article history:
Received 19 June 2013
Received in revised form
28 November 2013
Accepted 28 December 2013
Available online 8 January 2014

Keywords:
Initial breakdown
Cloud to ground discharges
Cloud discharges
Isolated breakdown

ABSTRACT

This paper investigates the existence of distinctive features between 4 different types of lightning discharges, namely negative cloud to ground discharge (−CG), positive cloud to ground discharge (+CG), cloud discharge (IC) and isolated breakdown discharge (IB). A total of 110 very fine structure waveforms of 44 −CG, 16 +CG, 39 IC, and 11 IB discharges have been selected from a collection of 885 waveforms measured using fast electric field broadband antenna system. The measurements were carried out in Uppsala, Sweden from May to August 2010. We found that there are significant distinctions within the first 1 ms among different types of lightning discharges (−CG, +CG, IC, and IB). For example, the pulses in −CG discharges are more frequent than other discharges; the pulses in +CG discharges have the highest intensity and the IC discharge pulses tend to have shorter duration.

1. Introduction

Any lightning discharge must be initiated with an electrical breakdown process. Thus breakdown process marks a starting point of all lightning discharges. However information regarding the initiation of the breakdown process is still not really well understood. Two hypothetical mechanisms have been proposed to explain the lightning initiation process in the cloud namely the conventional breakdown theory and the runaway breakdown theory (Gurevich and Zybin, 2005).

Initial breakdown process can be defined as an in-cloud process associated with lightning initiation that involves the formation of one or more channels in random directions by bridging two charge regions. Clarence and Malan (1957) suggested that electrical discharges occur when a vertical channel bridging the main negative charge centre (*N* region) and lower positive charge pocket (*p* region). Moreover, Proctor (1997) observed vertical channels bridging the main negative and main positive charge (*P* region) sources gave rise to electrical discharge process. On the other hand, Norinder and Knudsen (1956) and Krehbiel et al. (1979) suggested that horizontal channel extended from the main negative charge source gave rise to electrical discharges. In addition, Norinder and Knudsen (1956) also observed oblique channels extended from the main charge sources.

The breakdown process during lightning initiation could be grouped into three categories as suggested by Sharma et al. (2008). Breakdown process leading to cloud-to-ground discharge (CG) return strokes is the most common and well-studied category particularly the negative CG discharges (−CG). The initial breakdown process is believed to lead the initiation of the downward-moving stepped leader. Such breakdown process is commonly known as preliminary breakdown process (PBP) in CG flash. The second category is a breakdown process associated with cloud discharge (IC) and the final category is an isolated breakdown discharge (IB) that does not lead to any subsequent activities. Nag and Rakov (2009) have used different terms to describe IB process that is attempted first cloud-to-ground leaders.

Each breakdown process associated with CG, IC, and IB consists of train of pulses with both initial half-cycle polarities (Gomes and Cooray, 2004; Sharma et al., 2008). Furthermore, Sharma et al. (2008) observed that positive initial polarity pulses generally lead to the IC and negative initial polarity pulses generally lead to the −CG. In addition, Gomes and Cooray (2004) also observed that positive initial polarity pulses generally lead to the positive CG (+CG).

Sharma et al. (2008) have made comparison of initial breakdown processes between −CG, IC and IB captured from Swedish thunderstorms. They found that it is hard to differentiate between the negative initial polarity of IB and −CG breakdown pulses. Both of IB and −CG negative initial polarity breakdown process have comparable train duration, total number of pulses and inter-pulse duration (IPD). In contrast, the negative initial polarity of IC

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http://dx.doi.org/10.1016/j.jastp.2013.12.019

breakdown pulses has higher average total number of pulses compared to IB and −CG by a factor of 1.5. On the other hand, differences of the positive initial polarity breakdown process between −CG, IC and IB could be observed. The average total number of pulses of positive initial polarity of IB breakdown pulses is smaller compared to −CG and IC by a factor of 2.5 and 3.5, respectively.

Nag et al. (2009) and Nag and Rakov (2009) provided detail comparison of initial breakdown processes between −CG, IC, and IB captured from Florida thunderstorms. They observed the existence of submicrosecond-scale pulses in both −CG and IC but none have been observed in IB. The pulse duration (PD) for the majority of the pulses in −CG (> 78%) and IC (> 85%) was equal or less than 4 μs. In contrast, the average PD for IB breakdown pulses was 17. This implies that the initial breakdown pulses of −CG and IC contain "narrow" or "shorter" pulses compared to IB pulses. Furthermore, the average PD of −CG breakdown pulses was longer than IC by a factor of 1.3, which implies that the initial breakdown pulses of IC are narrower or shorter than −CG. Moreover, the average total number of pulses of IC breakdown process was higher than −CG with 110.25 compared to 58.83, which means that the initial breakdown pulses of IC is not only shorter but also more compact compared to −CG.

Gomes and Cooray (2004) made a comparison of initial breakdown processes between +CG and −CG captured from Swedish thunderstorms. They discovered that the leading edges of the initial half-cycle of +CG breakdown pulses were relatively smooth compared to −CG. Typically, the initial half-cycle of the −CG initial breakdown pulses are superimposed by a few sharp, narrow, unipolar pulses. They observed that their average PD was longer than previous study, 38 μs compared to 18.8 μs (Ushio et al., 1998). Ushio et al. (1998) have considered all the pulses in the breakdown train in their analysis while Gomes and Cooray (2004) only used selected largest pulses from the breakdown train and this reason may have contributed to the different values of average PD.

In all previous studies, the analysis was based on considering the whole duration of the train of breakdown pulses, which leads to the above observations and conclusions. In this paper, we are motivated to examine the very first moment of the breakdown process (within the first 1 ms). The individual pulses in the earliest part of the train may give useful information about lightning initiation process in the cloud and give us some clue on distinctive features that may exist leading to different lightning discharge processes. Moreover, we believe that there are no studies where all four types of initial breakdown processes leading to +CG, −CG, IC and IB lightning discharges were compared in a single analysis. Sharma et al. (2008), Nag and Rakov (2009), and Nag et al. (2009) have made comparison between −CG, IC and IB only while Gomes and Cooray (2004) provided comparison between +CG and −CG only.

2. Experimentation

The measurements were done in a stationary and fully grounded van (Fig. 1) located in the premise of Ångström Laboratory, Uppsala University, Sweden (59.8°N and 17.6°E) during summer thunderstorm between 25th of May and 31st of August 2010. The measuring station is situated at about 100 km from the Baltic Sea. The measuring system consists of three main parts as shown in Fig. 2, namely the parallel flat plate antenna unit, the buffer circuit unit and the recording unit (digital storage oscilloscope or DSO).

A set of broadband antenna system (together with a buffer circuit in the protected metal case beneath the parallel plate antenna) was installed approximately 2 m away from the van and mounted about 1.5 m above the ground plane using a grounded rod as shown in Fig. 3. The antenna was used to record the fast variation of vertical electric fields. To capture fast variation field, the buffer circuit unit was designed to have around 10 ns rise time and 15 ms decay time constants. The resistor R_2 and capacitor C values shown by the circuit schematic diagram in Fig. 4 determined the value of decay time constant. The upper and lower

Fig. 1. The measurement instruments are placed within fully grounded and protective metal van.

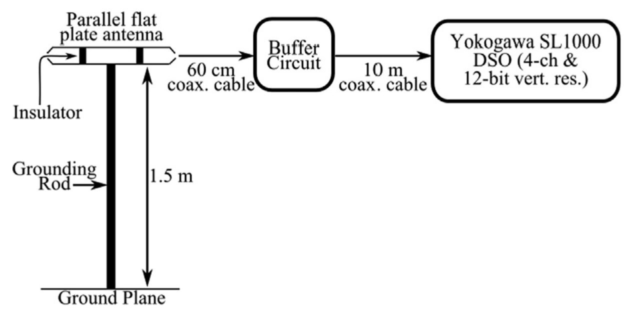

Fig. 2. The fast electric field broadband antenna system.

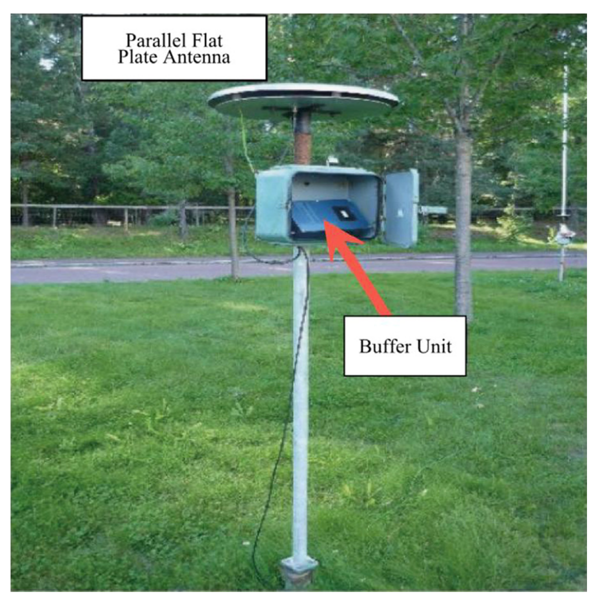

Fig. 3. Parallel flat plate antenna used for the measurement of fast electric field with the buffer circuit attached beneath it.